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[54] Method for manufacturing a semiconductor material integrated microactuator, in particular for a hard disc mobile read/write head, and a microactuator obtained thereby

(57) The integrated microactuator (1) has a stator (3) and a rotor (4) having a circular extension with radial arms (23, 6) which support electrodes (24, 12) extending in a substantially circumferential direction and interleaved with one another. For the manufacture, first a sacrificial region (34) is formed on a silicon substrate (2); an epitaxial layer (37) is then grown; the circuitry electronic components (45) and the biasing conductive regions (26, 43) are formed; subsequently a portion of substrate (2) beneath the sacrificial region (34) is removed, forming an aperture extending through the entire substrate; the epitaxial layer (37) is excavated to define and separate from one another the rotor (4) and the stator (3), and finally the sacrificial region (34) is removed to release the mobile structures from the remainder of the chip.

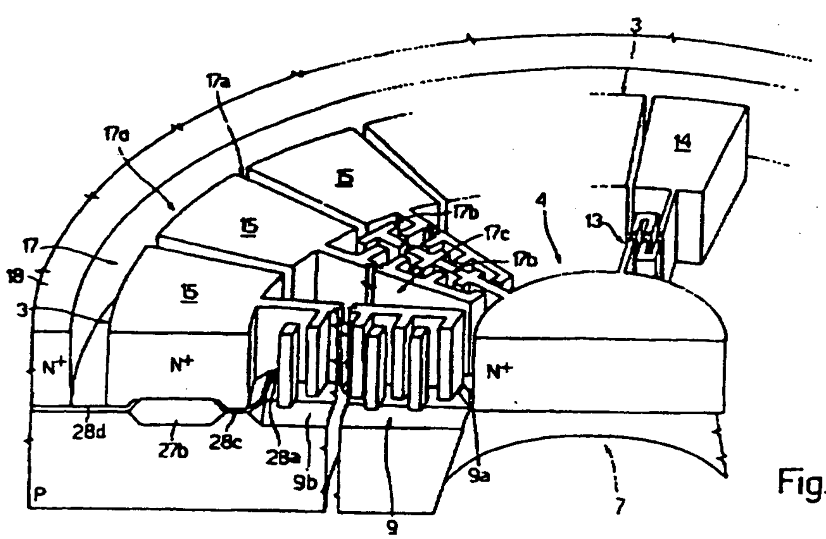

Fig5

EP 0 913 921 A1 CORRIGENDUM Issued on 04.08.1999 (bibliography updates included)

Description

[0001] The present invention relates to a method for manufacturing a semiconductor material integrated microactuator, in particular for a hard disc mobile read/write head, and the microactuator obtained thereby.

[0002] In hard disc read/write devices of a known type, the read/write heads are glued directly to the end of a steel suspension unit, which allows the head to be moved in the air at a predetermined distance from the disc, currently of approximately 30 nm.

[0003] To obtain more accurate and finer head position control, it has been proposed to arrange a microactuator between the head and the steel suspension unit. This microactuator must impart to the head (which generally has a weight of a few milligrams) an acceleration that is 20-30 times that of gravity; this means that the microactuator should be able to exert a force of approximately tenths of milliNewtons to be suitable for this purpose.

[0004] The microactuator must also be very flexible in a plane parallel to the disc, as well as being highly resistant in a perpendicular direction, to support the weight of the head (currently 1.5 mg), and to oppose the pressure generated during operation. In fact, as the disc rotates, a pressure profile is generated on the surface of the latter which tends to move the head away from the disc. On the other hand, if the head is moved away from the disc further than predetermined limits, the signal is so attenuated to make it impossible to read/write data; as a result, to maintain the required position, the suspension unit must currently exert on the head a direct force of approximately 2-3 g towards the disc.

[0005] The integrated microactuators available hitherto use actuation forces of electromagnetic and electrostatic nature.

[0006] Microactuators using electromagnetic forces are disadvantageous, since they require depositing of magnetic materials that are not commonly used in the microelectronics industry, and, since the data on the disc is stored by magnetising the disc surface, interference effects are possible between the data recording on the disc and the actuation mechanism. Furthermore, structures that use magnetic forces are more difficult to scale than those that use electrostatic forces.

[0007] Microactuators which use electrostatic type forces are preferable, both as regards the possibility of manufacturing the microactuators using conventional microelectronics production techniques, and because of the compatibility with the processes of reading and writing data on the disc.

[0008] Various solutions have been proposed for production of microactuators of an electrostatic type; according to a first solution, the elements of the actuator are produced by surface micromachining, i.e. by using surface layers deposited on a wafer of semiconductor material, or by electro-galvanic growth, or through ad hoc processes that differ from those normally used in microelectronics.

[0009] The technique of surface micromachining has the disadvantage that it does not allow manufacturing of structures having the above-described requirements, since the thinness of the polysilicon films which can be produced by common deposition techniques make the final structures not sufficiently rigid in a direction perpendicular to the disc; in addition, they cannot impart sufficient accelerating electrostatic force to the head, and are unstable since the edge effects are higher than the surface effects, and the system is less linear.

[0010] The system using galvanic growth, in which layers of metallic material are used, has the disadvantage that it has worse mechanical characteristics (in particular with reference to the yield strength σ), and is subject to hysteresis (whereas silicon does not have hysteresis); on the other hand the solution which uses ad hoc processes is difficult to industrialise, and has low yields.

[0011] The object of the invention is to provide a method and a microactuator which are free from the disadvantages of the solutions available hitherto.

[0012] According to the present invention, a method is provided for manufacturing a semiconductor material integrated microactuator, in particular for a hard disc mobile read/write head, and the microactuator obtained thereby, as defined respectively in claims 1 and 6.

[0013] For a better understanding of the present invention, a preferred embodiment is now described, purely by way of non-limiting example, with reference to the attached drawings, in which:

- figure 1 is a schematic plan view of the microactuator according to the invention;
- figure 2 is a detail of figure 1, on an enlarged scale;
- figures 3 and 4 are transverse cross-sections of details of the present microactuator, taken along section lines III-III and IV-IV of fig. 2;
- figure 5 is a cross-sectional and perspective view of the present microactuator; and
- figures 6-13 show transverse cross-sections through a semiconductor material wafer during successive steps of the present production method.

[0014] With reference to fig. 1, the microactuator 1 comprises an external stator 3, intended to be rigidly connected with a steel suspension unit (not shown), and an internal rotor 4, intended to be glued to a read/write head (not shown), coupled in a capacitive manner to the stator 3.

[0015] The rotor 4 comprises a suspended mass 5 which has a substantially circular shape and a plurality of mobile arms 6 extending radially towards the exterior starting from the suspended mass 5. In the illustrated example, the mobile arms 6 form four arm groups 6a identical to one another and extending each in a quadrant, and each arm group 6a comprises three mobile

arms 6, equidistant from one another. Each mobile arm 6 supports a plurality of elongate protrusions defining mobile electrodes 12 extending on both sides of the mobile arm 6 in a substantially circumferential direction (i.e. perpendicularly to the corresponding mobile arm 6), and equidistantly from one another.

[0016] The rotor 4 also comprises resilient suspension and anchorage elements, hereinafter calls simply "springs" 13, which are disposed between adjacent arm groups 6a, and connect the suspended mass 5 resiliently to fixed anchorage regions 14, biasing the rotor 4 and the mobile electrodes 12. In the shown embodiment, in plan view, each spring 13 is substantially S-shaped and has a constant width of 1-10 μm.

[0017] The stator 3 (whereof only part is shown in full, owing to the symmetry of the structure) comprises a plurality of fixed arms 23 with radial extension, each of which supports a plurality of elongate protrusions extending in a substantially circumferential direction (i.e. perpendicularly to the corresponding fixed arm 23), and defining fixed electrodes 24; in particular, two fixed arms 23 extend between two mobile arms 6 of each unit 6a, and the fixed electrodes 24 extend from each fixed arm 23 only on the side thereof facing the mobile arm 6 and are intercalated or interleaved with the mobile electrodes 12.

[0018] The fixed arms 23 extend from fixed regions 15 which are disposed annularly around the rotor 4, and are intercalated with the anchorage regions 14.

[0019] In the microactuator in fig. 1, the fixed electrodes 24 and mobile electrodes 12, which are interleaved with one another, form a plurality of parallel arranged capacitors. When voltage drops ΔV_1, ΔV_2, are applied between two fixed arms 23 facing a same mobile arm 6, and the mobile arm 6 itself, owing to capacitive coupling each mobile arm 6 is subjected to a transverse force that tends to move it away from the arm 23 set at the nearer potential, and to bring it closer to the other arm 23 at a greater ΔV, causing rotation of the suspended mass 5, with resilient deformation of the springs 13. The extent of the force F acting on the rotor 4 is equal to:

$$F = a \cdot \varepsilon_0 \cdot N \cdot t \cdot \Delta V^2 / g$$

wherein $\underline{a}$ is a shape factor depending on the system geometry, ε_0 is the electrical permeability of the air, N is the number of interleaved electrodes 12, 24; $\underline{t}$ is the thickness of the structure measured perpendicularly to the sheet and $\underline{g}$ is the gap between each mobile electrode 12 and the two facing fixed electrodes 24 (see fig. 2 in which the arrows D represent the direction of movement of the mobile arms 6 and the corresponding mobile electrodes 12).

[0020] Therefore, owing to actuation in a parallel direction to the electrodes, a very stable structure is obtained, since the force is independent of the overlapping between the mobile and the fixed teeth (in the case of actuation in a perpendicular direction, with variation of the active gap between the electrodes, the force depends on the inverse of the square of the active distance $\underline{g}$, and a force which is so greatly non-linear causes the presence of a limit voltage beyond which the resilient reaction is no longer sufficient to keep the stator separate from the rotor); in addition, use of a circular structure with rotatory, non-linear movement, makes it possible to obtain a system which is less sensitive to the acceleration transmitted by the suspension unit during operation, for example during the search for the track.

[0021] A preferred embodiment of the present actuator is now described with reference to figs. 2-5.

[0022] The rotor 4 comprises N^+-doped polycrystalline silicon obtained from an epitaxial layer 37 (as described in detail hereinafter) above an aperture 7 provided in a substrate 2 of the device; an air gap 9 is provided between the substrate 2 and the epitaxial layer 37 and comprises an annular region 9a and a plurality of star-like arms 9b. In particular, the annular region 9a extends without interruption from the aperture 7, radially towards the exterior of the aperture 7, and the star-like arms 9b extend below the mobile arms 6, the corresponding mobile electrodes 12 and the fixed electrodes 24 which face the latter, in radial direction. As an alternative to the embodiment shown, the air gap 9 can have a completely annular shape extending not only below the components 6, 12, and 24, but also below the fixed arms 23, at the interface between the substrate 2 and the epitaxial layer 37.

[0023] The anchorage regions 14 and the fixed regions 15 are also formed in the epitaxial layer 37, and are disposed annularly around the suspended mass 5. The fixed regions 15 are separated from one another and from the anchorage regions 14 by radial portions 17a of a trench 17 that also has zig-zag portions 17b, and wedge-shaped portions 17c; the zig-zag portions 17b extend generally in a radial direction and separate from one another the mobile arms 6, the fixed arms 23, the mobile electrodes 12 and the fixed electrodes 24; the wedge-shaped portions 17c extend between the two fixed arms 13 which are adjacent to one another and face different mobile arms 6.

[0024] The anchorage regions 14 and the fixed regions 15 are surrounded by a bulk region 18 that has an annular shape of N^+-type, also formed in the epitaxial layer 37, and separated from the regions 14 and 15 by a circular portion 17d of the trench 17. As can be seen in particular in the detail of fig. 2 and in the sections in figs. 3 and 4, the bulk region 18 is surrounded by a polycrystalline epitaxial region 20 of P-type, which in turn is surrounded by a monocrystalline region 21 embedding the external circuitry of the microactuator 1.

[0025] A buried contact region 25 of N^+-type extends below each fixed arm 23 and the corresponding fixed region 15, inside the substrate 2 and near its surface 22 of interface with the epitaxial layer 37; the buried contact region 25 continues below the bulk region 18, the poly-

crystalline epitaxial region 20, and part of the monocrystalline region 21, where it is in electrical contact with a sinker region 26 extending from the surface 30 of the epitaxial layer 37. At the fixed arms 23, the buried contact regions 25 are surrounded by buried oxide regions 27a (see in particular figs. 2 and 3), which, at the fixed region 15, become wider and have a generally T-shape with a head 27b. Each buried oxide region 27a is in turn surrounded by a U-shaped section 28a of a silicon nitride insulation region 28f, which, at the fixed regions 15 and the anchorage regions 14, widens to define circumferential sections 28b that connect pairs of adjacent U-shaped sections 28a; the circumferential sections 28b are continued by radial sections 28c which extend below the radial portions 17a of the trench 17; in turn, the radial sections 28c are connected to a circular section 28d, which extends partially beneath the fixed regions 15 and the anchorage regions 14, beneath the circular portion 17d of the trench 17, and beneath part of the bulk region 18. A buried oxide region 27c (which can be seen in figs. 2 and 4) extends below the interface between the bulk region 18 and the polycrystalline epitaxial region 20, is surrounded by a nitride region 28e extending along the interface surface 22 and insulates the buried contact region 25 from the epitaxial layer. The nitride region 28e extends near the outer edge of the polycrystalline epitaxial region 20, as can be seen in fig. 2. In addition, as can be seen in fig. 4, a trench 29 with a closed rectangular shape, extending inside the polycrystalline epitaxial region 20 from the surface 30 as far as the nitride region 28e, separates the microactuator 1 electrically from the remainder of the device.

[0026] The method for production of the microactuator 1 is described hereinafter with reference to figs. 6-13, in which the thicknesses of the various layers of material are not to scale, and some layers are not shown in all the figures, for sake of representation.

[0027] As shown in fig. 6, in the monocrystalline silicon substrate 2, the buried contact regions 25 of N^+-type are formed by conventional masking and implantation techniques. On the interface surface 22 of the substrate 2 a pad oxide layer 32 is then formed, for example thermally grown, and above the latter a silicon nitride layer 28 is deposited; the silicon nitride layer 28 is then defined and removed selectively in order to obtain protective regions 28z. Subsequently, the portions of the surface of the substrate 2 which are not covered by the protective regions 28z are locally oxidized and form oxide regions including a sacrificial region 34, and the buried oxide regions 27a, 27b, 27c (of which only the first two can be seen in fig. 7), thus providing the structure of fig. 7.

[0028] Subsequently, by means of masking steps, the portions of the layers 32, 28 are removed where the contacts are to be formed for the fixed regions 15, for the fixed arms 23 and for the bulk region 18 and the portions of the silicon nitride layer 28 are removed in the circuitry area, thus providing the structure of fig. 8, in which the pad oxide layer 32 that is below the silicon nitride layer 28 is not shown, and in which the sections 28a and 28d of the nitride region 28f, and part of the nitride region 28e can be seen.

[0029] Then, a polycrystalline or amorphous silicon layer 35 is deposited as shown in fig. 9. Through a phototechnical and plasma etching steps, the polycrystalline or amorphous silicon layer 35 is removed from the exterior of the actuator area 36, forming a silicon region 35' which constitutes the seed for the subsequent epitaxial growth.

[0030] Subsequently, by etching, the pad oxide layer 32 is removed where it is exposed, and epitaxial growth is carried out with formation of the pseudo-epitaxial layer 37 of P-type which, above the silicon region 35', has a polycrystalline structure (polycrystalline region 37') and elsewhere has a monocrystalline structure (which constitutes the monocrystalline region 21). A wafer 39 is thus obtained, as shown in fig. 10.

[0031] Subsequently, the pseudo-epitaxial layer 37 is doped with doping ions which give rise to N-type conductivity to form sinker regions; in particular, as shown in fig. 11, in the monocrystalline region 21, the sinker region 26 of N^+-type is formed and extends from the surface 30 of the wafer 39 as far as the buried contact region 25. In addition, in the polycrystalline region 37' a well 43 of N^+-type is formed, which is designed to define the suspended mass 5, the mobile and fixed arms 6, 23, the mobile and fixed electrodes 12, 24, the fixed regions 15, the anchorage regions 14 and the bulk region 18, and which also extends from the surface 30 as far as the substrate 2, contacting electrically the buried contact region 25.

[0032] Subsequently, by means of standard steps, the electronic components of the circuitry are formed; in the illustrate example, a collector well 44 of N-type is formed, which extends in the interior of the monocrystalline region 21, from the surface 30 of the wafer 39 as far as the substrate 2; in the collector well 44 an NPN transistor 45 is formed which has a collector contact region 46 of N^+-type, a base region 47 of P-type and an emitter region 48 of N^+-type.

[0033] On the surface 30 of the wafer 39, a dielectric layer 49 is then deposited for contact opening and comprise for example BPSG (Boron Phosphorous Silicon Glass). Then, by a masking and selective removing step, contacts are opened in the circuitry area and on the sinker region 26, and the dielectric layer 49 is removed in the actuator area 36; subsequently, a metallic layer is deposited and shaped, to form circuitry contacts 50 and the sinker regions 26.

[0034] Then a passivation dielectrode layer 51 is deposited and removed from the area of the contact pads (to allow electrical contacting of the device, in a manner not shown) and in the microactuator area 36, thus providing the structure of fig. 11.

[0035] Subsequently, by means of a photolithographic step, areas are defined on the wafer back and TMAH

(tetramethylammoniumhydrate) etching is carried out on the back of the wafer 39, to remove the portion of substrate 2 which is beneath the sacrificial region 34; the etching stops automatically on the sacrificial region 34, providing the aperture 7 as shown in fig. 12.

[0036] Subsequently, using an appropriate resist or deposited oxide mask, the trench 17 is excavated for shaping the suspended mass 5, the mobile and fixed arms 6, 23, and the mobile and fixed electrodes 12, 24, and for separating the biased regions at different voltages. In addition, the trench 29 is excavated.

[0037] Finally, the sacrificial region 34 is removed by buffered hydrofluoric acid etching, such as to provide the air gap 9, and release the mobile arms and the mobile and fixed electrodes 12, 24. Then the final structure shown in fig. 13 is obtained.

[0038] The advantages of the described microactuator and production method are as follows. Being formed from the epitaxial layer, the microactuator has the high quality mechanical features required; by using electrostatic type actuation forces and owing to the described circular structure, there is no risk of interference with the read/write processes on the magnetic disc, and the actuator is not much sensitive to stresses. In addition, the specific shape of the electrodes reduces the risk, which exists in other types of shapes, of stiction of the rotor on the stator in the presence of high biasing. The use of manufacturing techniques conventional for integrated electronics makes the structure cheap and repeatable, and allows integration on the chip of the associated circuitry.

[0039] Finally, it will be apparent that changes and variants can be made to the method described and illustrated here, without departing from the scope of the present invention, as defined in the attached claims.

Claims

1. A method for manufacturing an integrated microactuator (1), characterised in that it comprises the steps of:

   - growing an epitaxial layer (37) on a substrate (2), thereby obtaining a semiconductor material wafer (39);
   - removing selective portions of the epitaxial layer (37), thereby forming a rotor element (4) and a stator element (3) facing one another and capacitively coupled to one another; and
   - removing a portion of the substrate (2) below the rotor element (4) by back-etching, thereby forming an aperture (7) in the substrate.

2. A method according to claim 1, characterised in that before the step of growing an epitaxial layer (37), the step is carried out of forming a sacrificial region (34) on the substrate (2) at the rotor element (4), and in that the step of removing a portion also comprises the step of removing the sacrificial region (34) thereby forming an air gap (9).

3. A method according to claim 1 or claim 2, wherein the substrate (2) and the epitaxial layer (37) have a first conductivity type, characterised in that before the step of growing an epitaxial layer (37), the steps are carried out of forming, in the substrate (2), buried contact regions (25) with a second conductivity type and, on the buried contact regions (25), electrically insulating material regions (27; 28) delimiting between one another selective contact portions of the buried contact regions (25); in that, after the step of growing an epitaxial layer (37), the step is carried out of forming a well (43) with the second conductivity type, at the stator and rotor elements (3, 4), and sinker contact regions (26) extending laterally to the well (43) from a surface (30) of the epitaxial layer (37), as far as buried contact regions (25), thereby forming sinker contact regions.

4. A method according to any one of the preceding claims, characterised in that before the step of removing selective portions of the epitaxial layer (37), the step is carried out of forming electronic components (45) in the epitaxial layer (37)

5. A method according to any one of the preceding claims, characterised in that the step of removing selective portions of the epitaxial layer (37) comprises the step of forming a trench (17) extending throughout the depth of the epitaxial layer (37), and forming a suspended mass (5), said suspended mass having a substantially circular shape and supporting mobile arms (6) which extend radially and have first extensions (12) extending in a substantially transverse direction on both sides of the mobile arms 6, and being interleaved with corresponding second extensions (24) extending in said substantially transverse direction from corresponding fixed arms (23) extending radially and integrally with corresponding fixed regions (15) supported by the substrate (2).

6. A semiconductor material integrated microactuator having a circular structure, comprising a stator element (3) and a rotor element (4) electrostatically coupled to each other by respective mobile and fixed electrodes (12, 24) and supported by a substrate (2) of semiconductor material, characterised in that the stator and rotor elements (3, 4) are formed by portions of an epitaxial layer (37) of semiconductor material having trenches (17) separating from one another the rotor and stator elements, as well as conductive regions (15, 18).

7. A microactuator according to claim 6, characterised in that the rotor element (4) comprises a suspended

mass (5) arranged centrally and supporting mobile arms (6) extending radially and supporting first transverse extensions on both sides; in that the stator element (3) comprises fixed regions (15) formed in the epitaxial layer (37) and supporting corresponding fixed arms (23) extending radially towards the suspended mass (5) and having second extensions (24) which extend in a transverse direction from one side of each fixed arm (23), and are interleaved with the first extensions (12); the fixed regions (15) being supported by the substrate (2) and being electrically insulated from the substrate by insulating material regions (27, 28).

8. A microactuator according to claim 7, characterised in that each mobile arm (6) is associated to two fixed arms (23) extending on different sides of the mobile arm; the two fixed arms (23) associated with a same mobile arm (6) being biased to a different potential.

9. A microactuator according to claim 7 or 8, characterised in that the suspended mass (5) is supported by resilient suspended arms (13) extending between the suspended mass and anchorage regions (14) adjacent to, and electrically insulated from the fixed regions (15), the anchorage regions (14) being supported by the substrate (2).

10. A microactuator according to any one of claims 6-9, characterised in that the substrate (2) has an aperture (7) extending below the rotor element (4).

11. A microactuator according to any one of claims 7-9, characterised in that the substrate (2) has a through aperture (7) below the suspended mass (5); and in that an air gap (9) extends between the substrate (2) and the epitaxial layer (37), at least below the mobile arms (6) and the second extensions (12).

12. A microactuator according to claim 9, characterised in that the substrate (2) has a first conductivity type, in that the epitaxial layer (37) comprises a polycrystalline region (43) with a second conductivity type accommodating the stator and rotor elements (3, 4), and a monocrystalline region (21) of the first conductivity type, which are adjacent to one another; and in that sinker contact regions (26) of the second conductivity type extend in the monocrystalline region (21) between an upper surface (30) and the substrate (2), and buried contact regions (25) extend in the substrate (2) between the fixed regions (15) and the anchorage regions (14) on the one hand, and the sinker contact regions (26) on the other hand.

13. A microactuator according to claim 12, characterised in that the buried contact regions (25) comprise first buried contact regions having a biasing section extending below and in electrical contact with the fixed arms (23), the biasing regions being surrounded on at least two sides by electrically insulating regions (27a).

14. A microactuator according to claim 12 or claim 13, characterised in that it comprises electronic components (45) provided in the monocrystalline region (21).

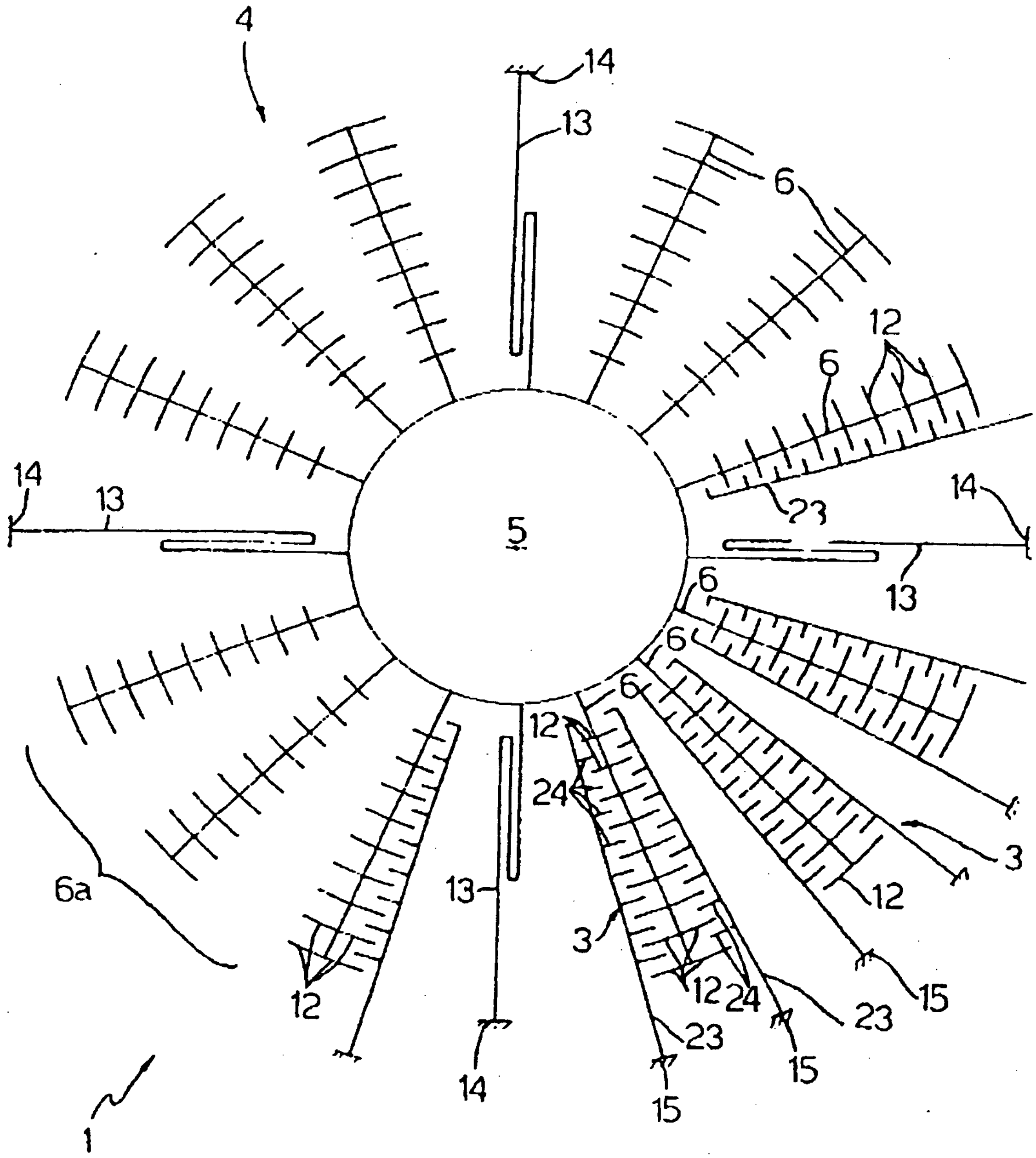
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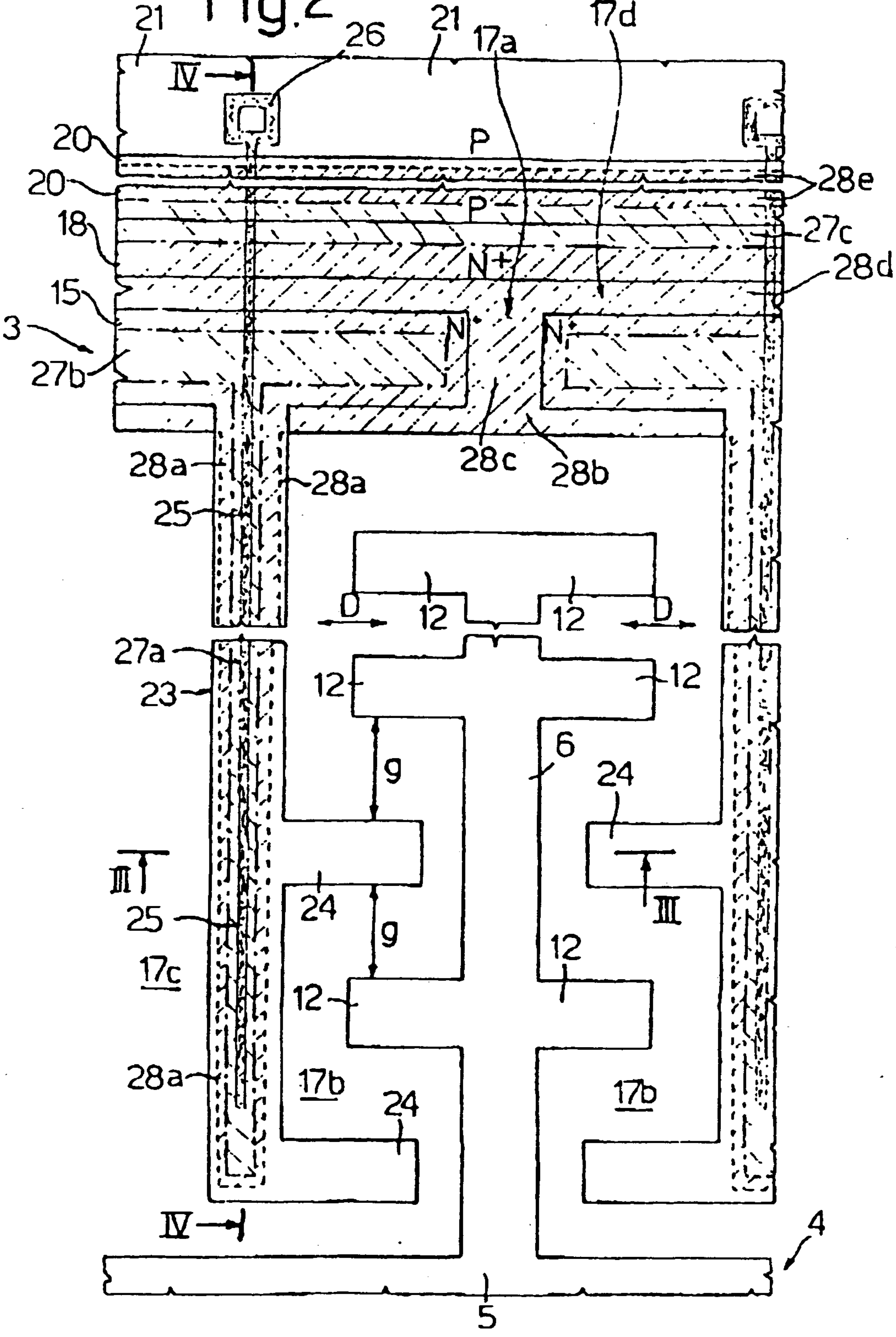
Fig.1

Fig.2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17d
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P
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P
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28d
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27b
28a
28a
28c
28b
25
D
12
12
D
27a
23
12
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Fig.3

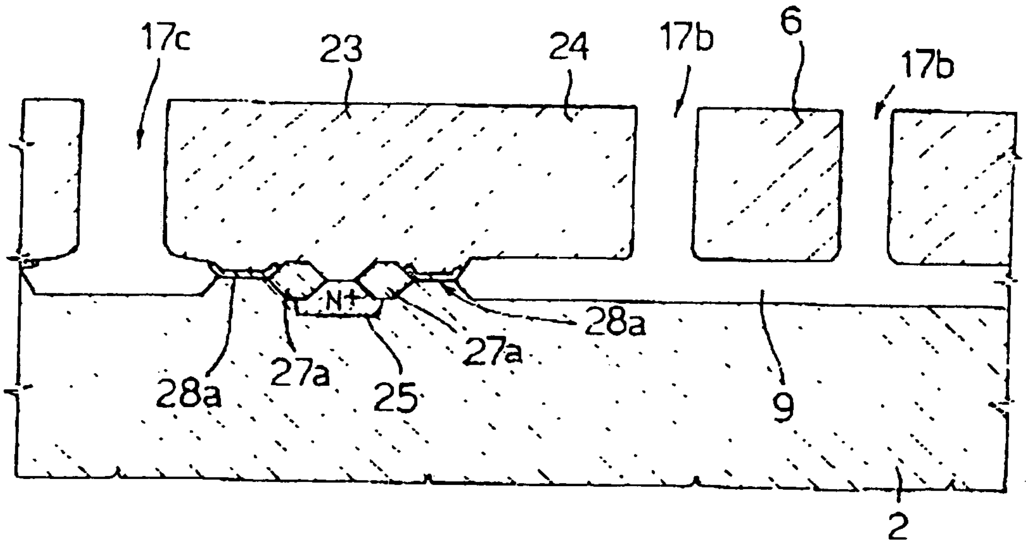
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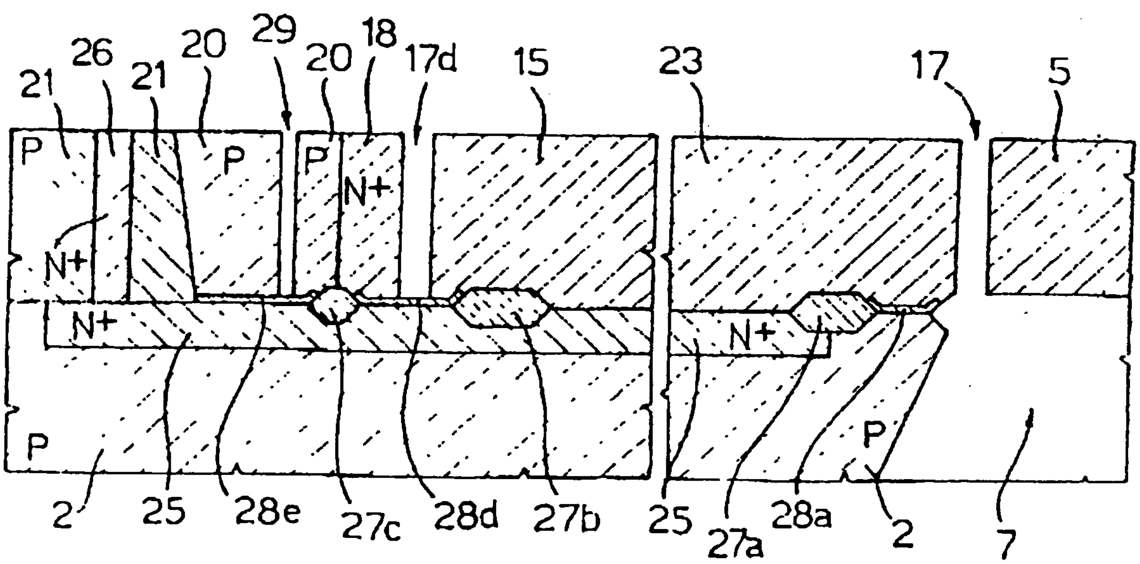
Fig.4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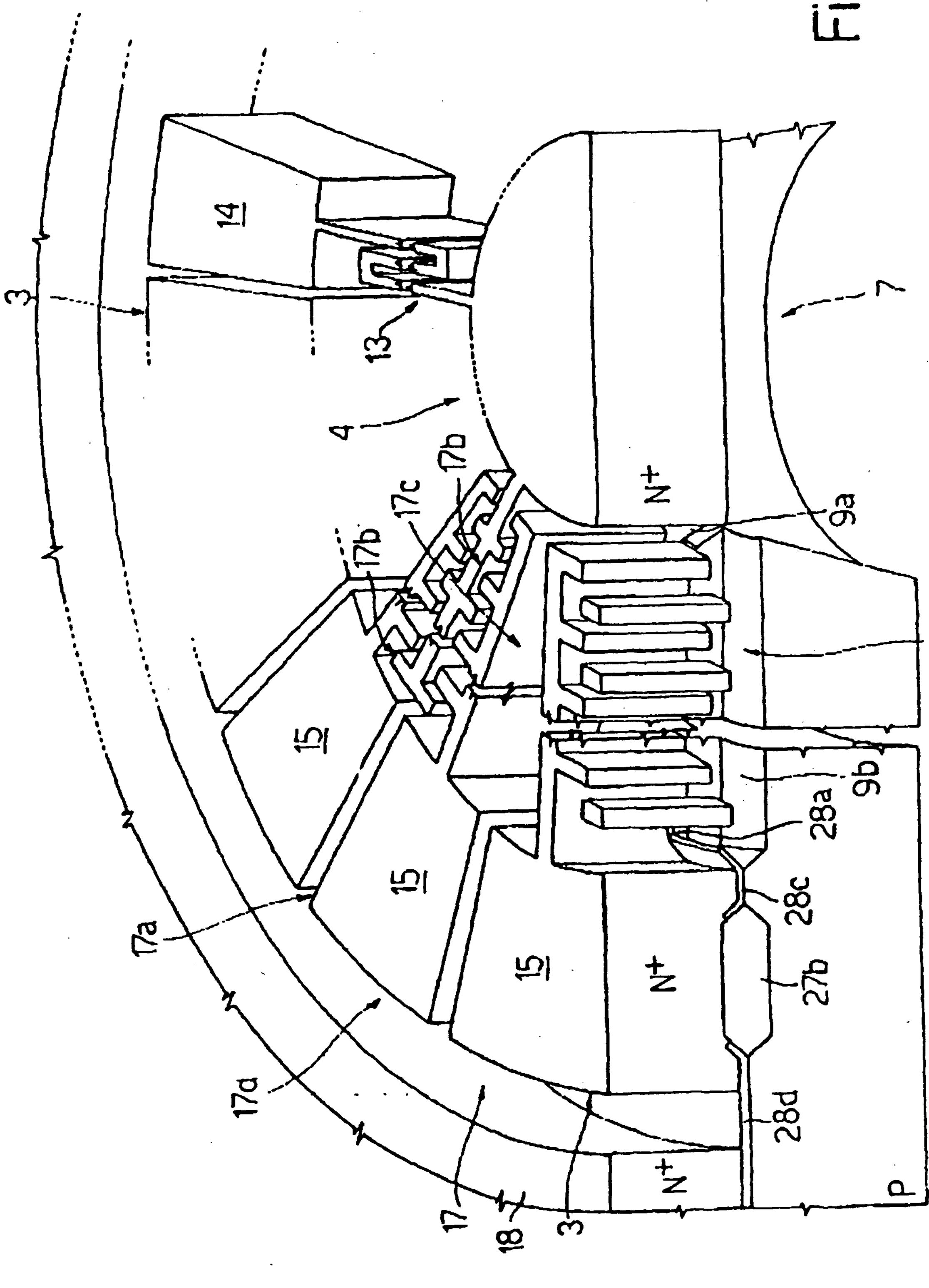
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Fig5

Fig.6

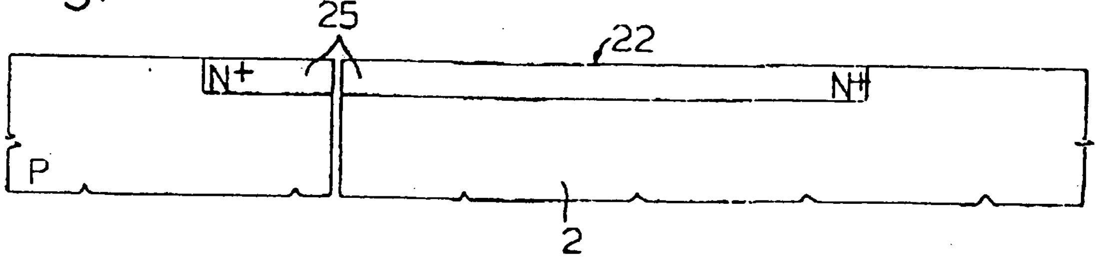


Fig.7

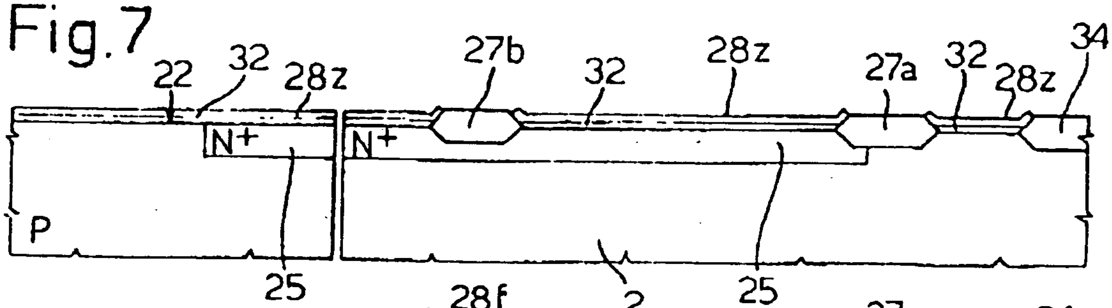


Fig.8

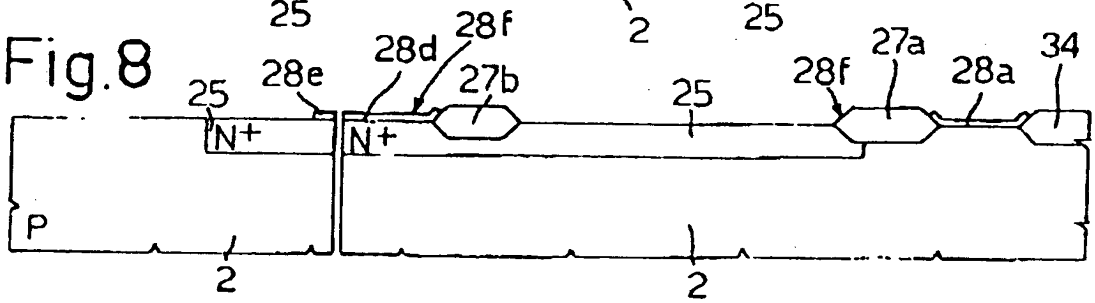


Fig.9

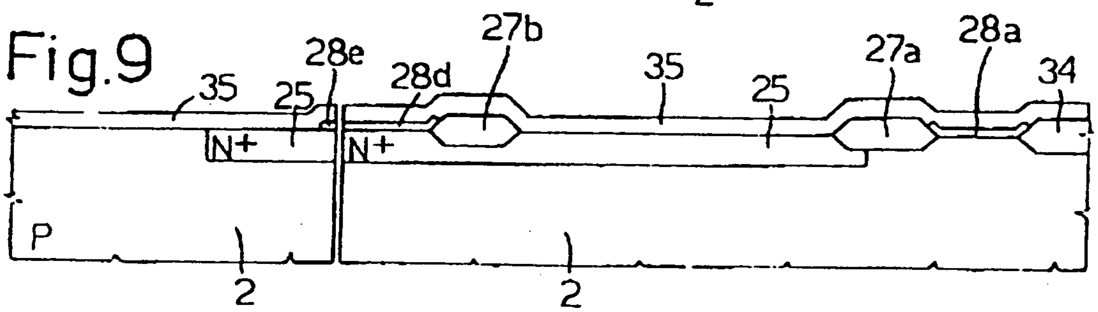
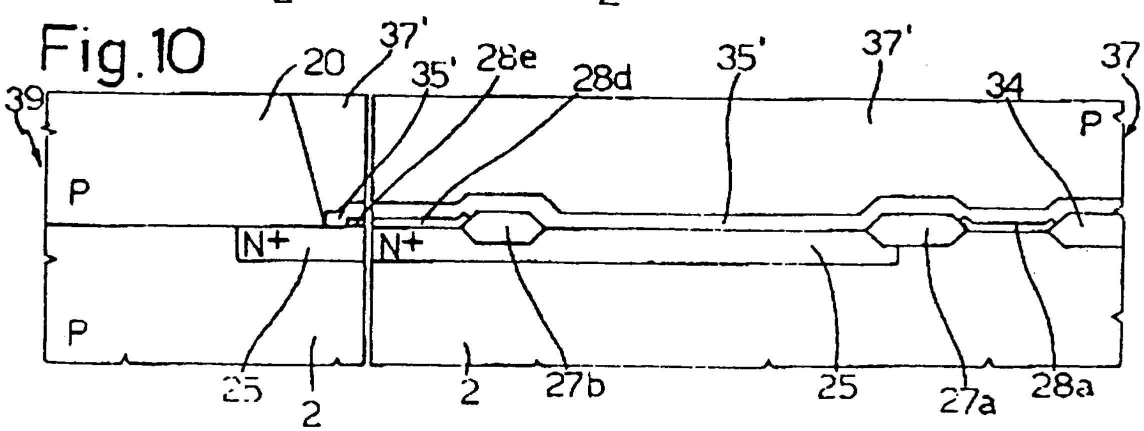


Fig.10



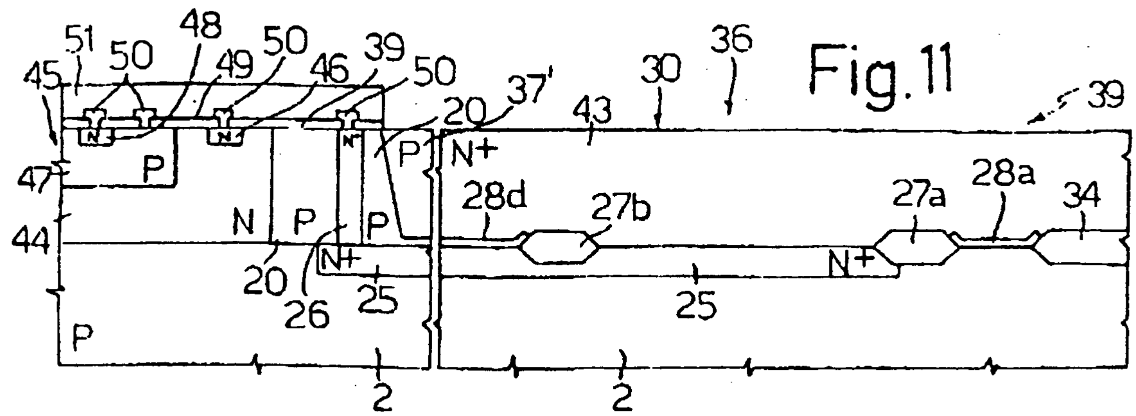


Fig.11

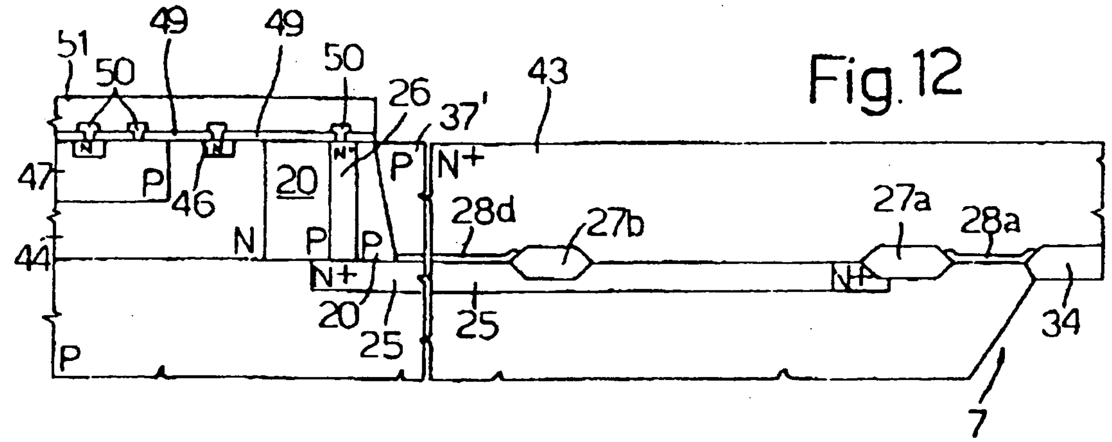


Fig.12

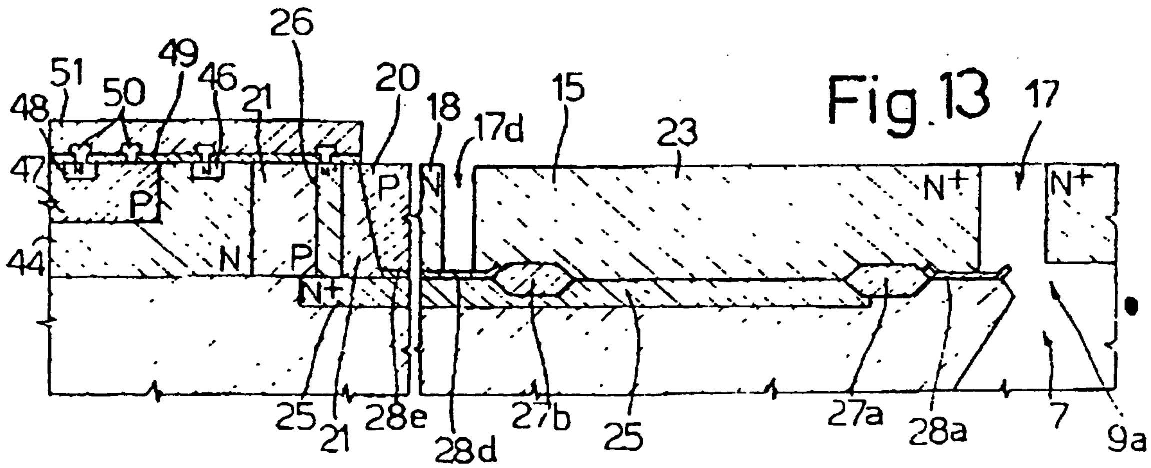


Fig.13

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EUROPEAN SEARCH REPORT

Application Number
EP 97 83 0556

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	30 March 1998	Ramos, H

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